

Gases

Properties of Gases

assume the volume and shape of their containers

most compressible of the states of matter

mix evenly and completely with other gases

much lower density than other forms of matter

Substances that Exist as Gases

Group	1	2		3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
	1A	2A		3B	4B	5B	6B	7B		8B		1B	2B	3A	4A	5A	6A	7A	8A
Period																			
1	1 H																		2 He
2	3 Li	4 Be												5 B	6 C	7 N	8 O	9 F	10 Ne
3	11 Na	12 Mg												13 Al	14 Si	15 P	16 S	17 Cl	18 Ar
4	19 K	20 Ca		21 Sc	22 Ti	23 V	24 Cr	25 Mn	26 Fe	27 Co	28 Ni	29 Cu	30 Zn	31 Ga	32 Ge	33 As	34 Se	35 Br	36 Kr
5	37 Rb	38 Sr		39 Y	40 Zr	41 Nb	42 Mo	43 Tc	44 Ru	45 Rh	46 Pd	47 Ag	48 Cd	49 In	50 Sn	51 Sb	52 Te	53 I	54 Xe
6	55 Cs	56 Ba	*	71 Lu	72 Hf	73 Ta	74 W	75 Re	76 Os	77 Ir	78 Pt	79 Au	80 Hg	81 Tl	82 Pb	83 Bi	84 Po	85 At	86 Rn
7	87 Fr	88 Ra	**	103 Lr	104 Rf	105 Db	106 Sg	107 Bh	108 Hs	109 Mt	110 Uun	111 Uuu	112 Uub	113 Uut	114 Uuq	115 Uup	116 Uuh	117 Uus	118 Uuo
lanthanides			*	57 La	58 Ce	59 Pr	60 Nd	61 Pm	62 Sm	63 Eu	64 Gd	65 Tb	66 Dy	67 Ho	68 Er	69 Tm	70 Yb		
actinides			**	89 Ac	90 Th	91 Pa	92 U	93 Np	94 Pu	95 Am	96 Cm	97 Bk	98 Cf	99 Es	100 Fm	101 Md	102 No		

Elements that exist as gases at 25°C and 1 atm. The Noble gases (the Group 8A elements) are monatomic species; the other elements exist as diatomic molecules. Ozone (O₃) is also a gas.

Some substances found as gases at 1 atm and 25 °C

Elements

H₂, N₂, O₂, O₃, F₂, Cl₂

He, Ne, Ar, Kr, Xe, Rn

Compounds

HF, HCl, HBr, HI, CO, CO₂, NH₃, NO,

NO₂, N₂O, SO₂, H₂S, HCN

Pressure of a Gas

Pressure

The force exerted on an object divided by the surface area of the object;

$$P = \frac{F}{A}$$

Any gas confined to a container is found to exert a pressure on the container .

SI Units of Pressure

customary units

$$\begin{aligned} 1 \text{ standard atm} &= 760 \text{ mm Hg} \\ &= 760 \text{ torr} \end{aligned}$$

SI units

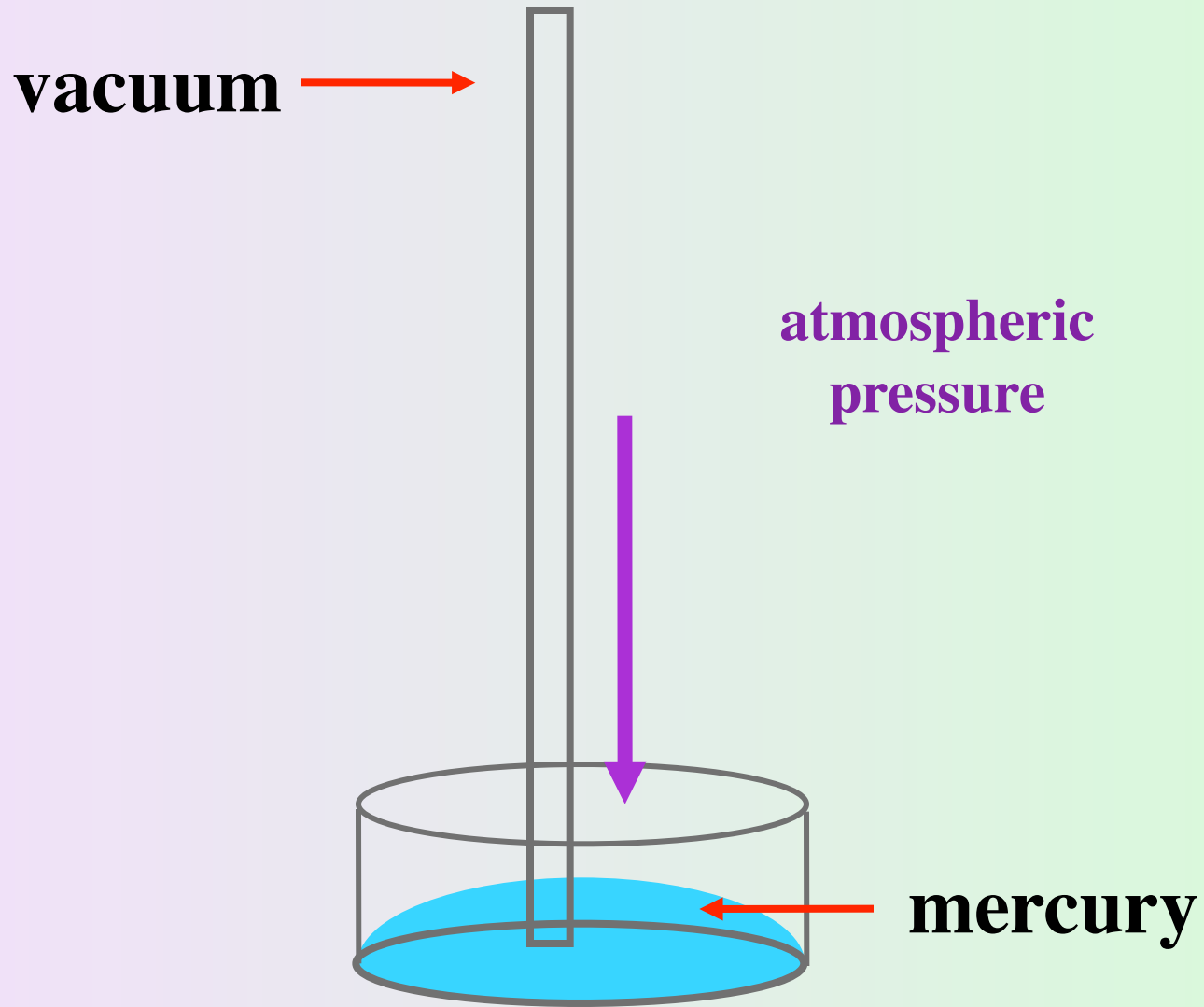
pressure = force/area

pressure = Newton/m² = Pascal

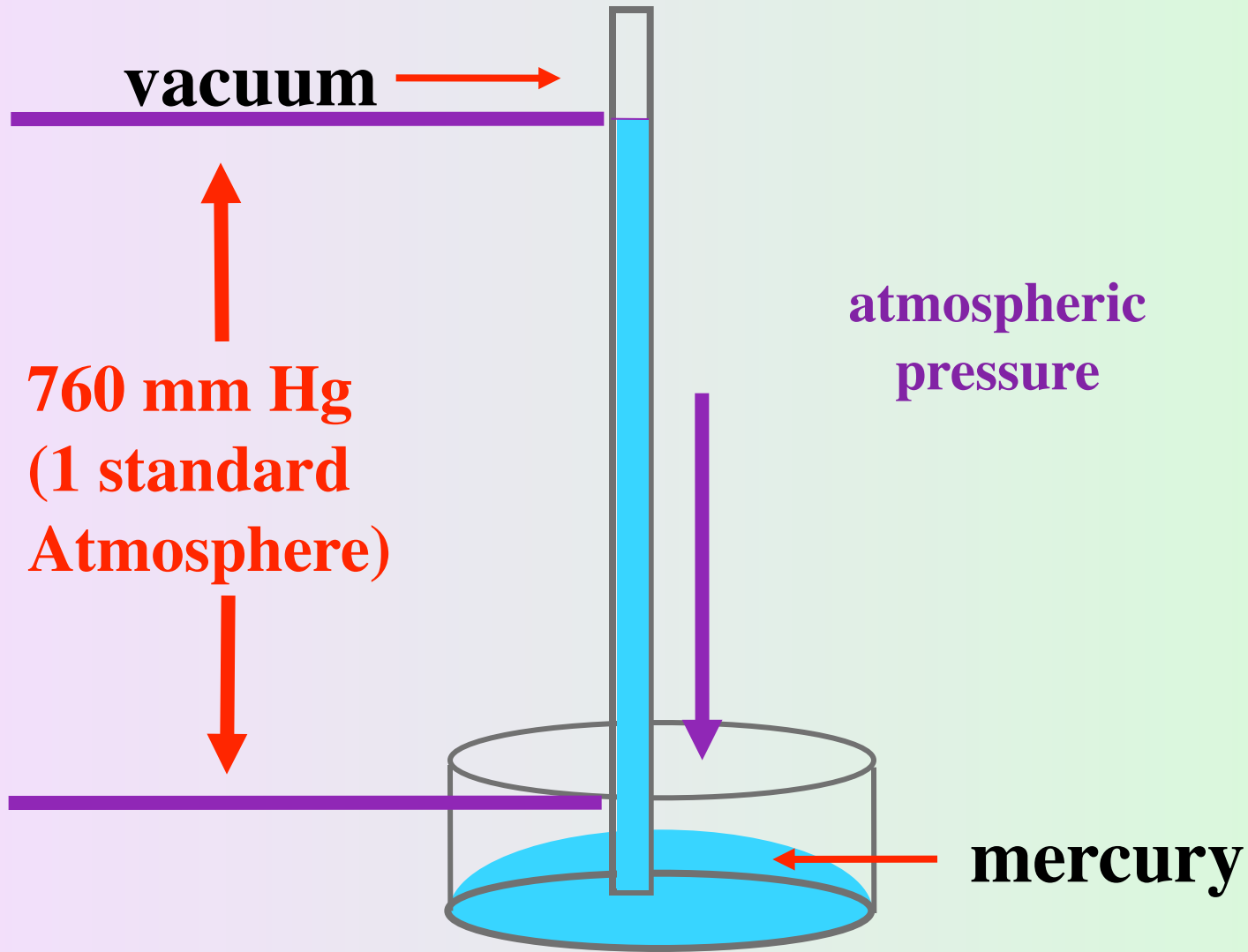
1 standard atmosphere = 101,325 Pa

or

1 atm = 101.3 kPa



A Torricellian Barometer



A Torricellian Barometer

The Gas Laws

Boyle's Law

Charles' Law

Avogadro's Law

The Ideal Gas Law

The Gas Laws and the Scientific Method

Observations

Laws

Theory

Hypothesis

Experiment

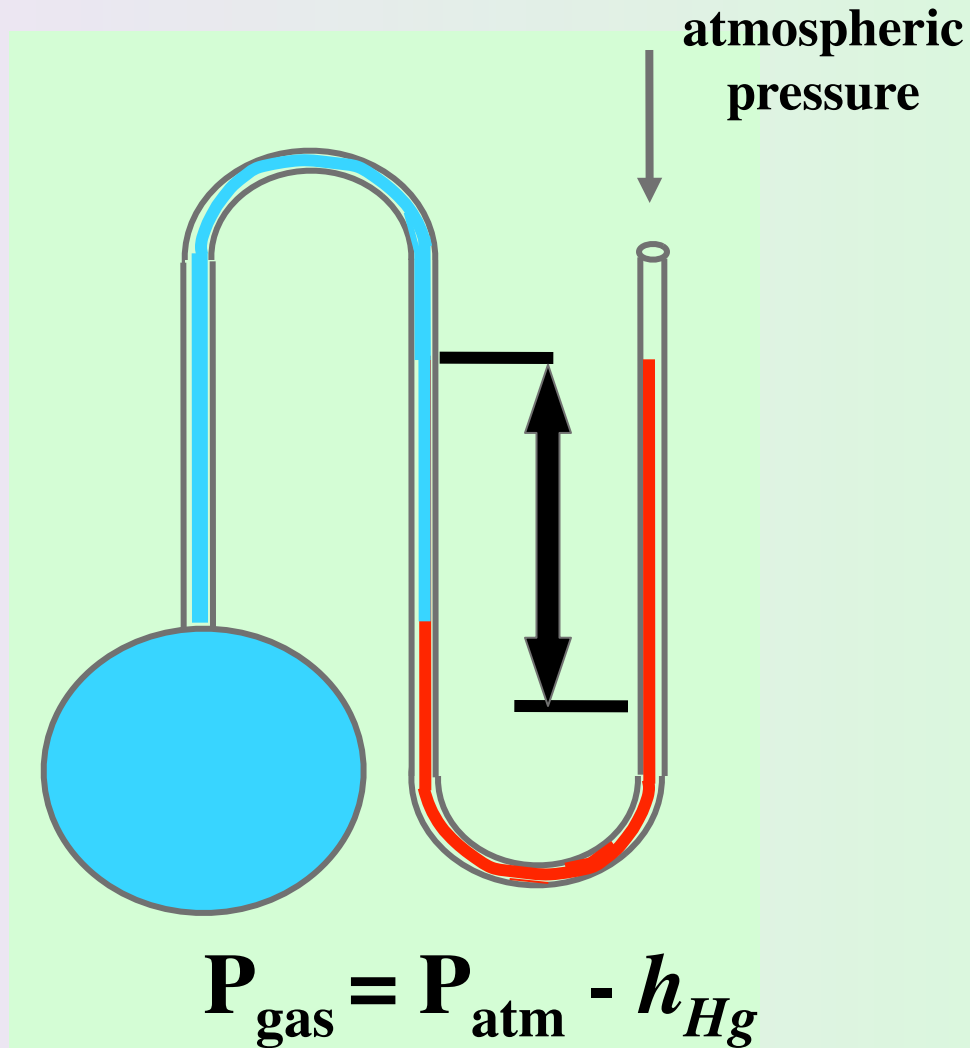
**Boyle
Charles
Avogadro
Ideal Gas**

**Kinetic-
molecular theory**

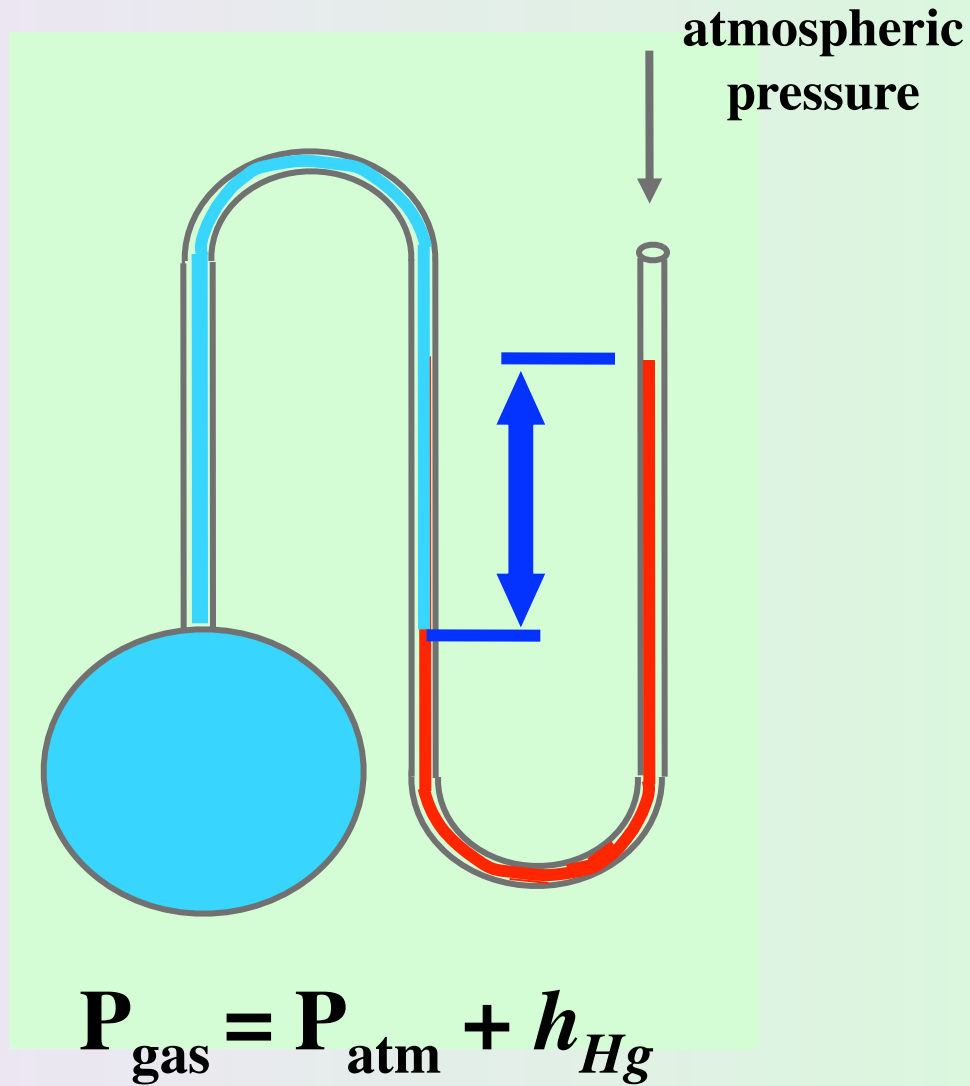
Boyle's Law

Robert Boyle 1626 – 1691

Manometer

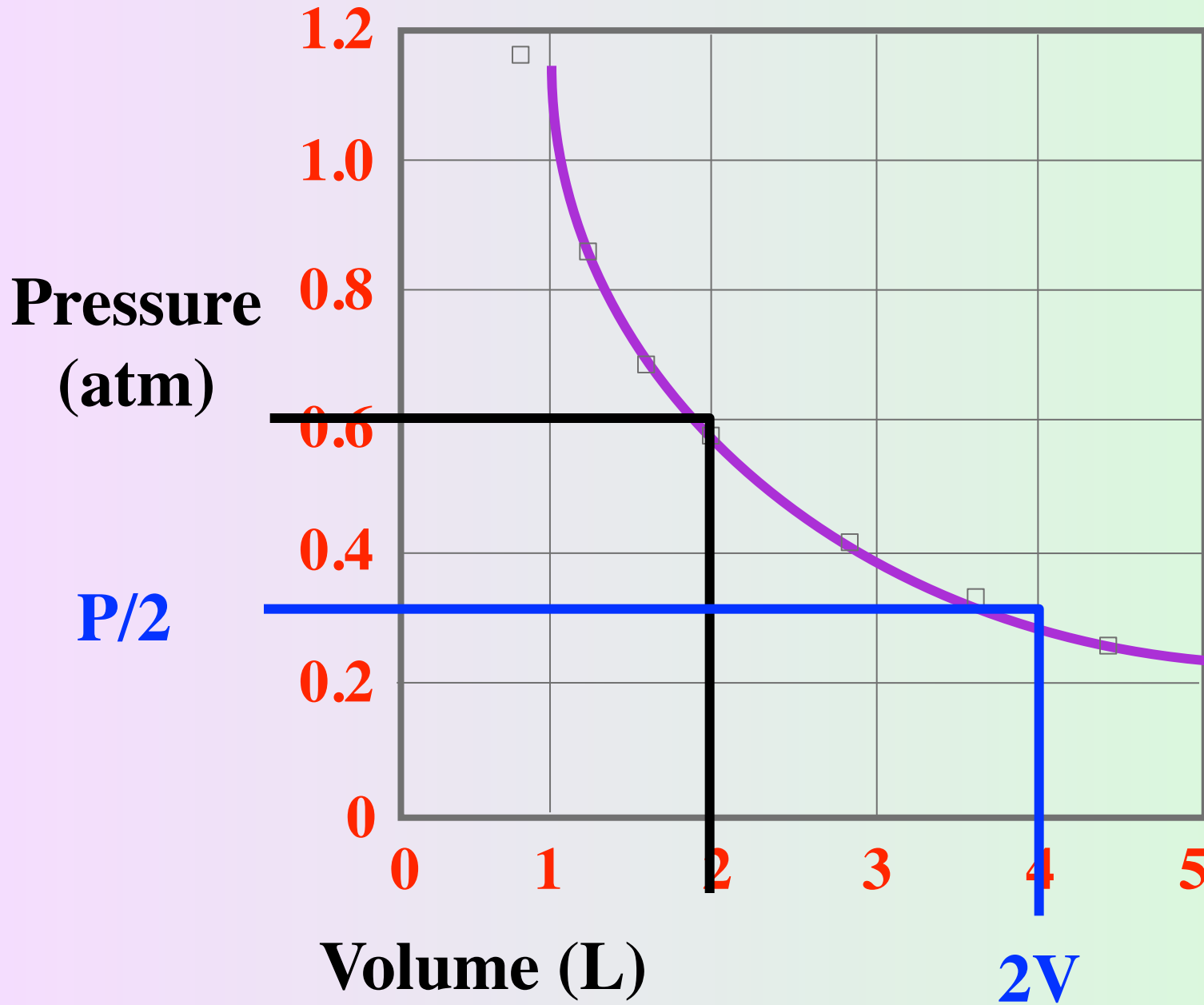


Manometer



Boyle's Data

Pressure (mm Hg)	Volume (arbitrary units)
724	1.50
869	1.33
951	1.22
998	1.16
1230	0.94
1893	0.61
2250	0.51



Boyle's Data

Pressure (mm Hg)	Volume (arbitrary units)	PV
724	1.50	1090
869	1.33	1160
951	1.22	1160
998	1.16	1160
1230	0.94	1200
1893	0.61	1200
2250	0.51	1100

Boyle's Law

at constant temperature, the volume of a constant amount of gas is inversely proportional to the pressure

constant n , constant T

$$PV = k$$

$$P = k \frac{1}{V}$$

pg.422 problem 2

The pressure of a sample of helium in a 1.00 L container is 0.988 atm. What is the new pressure if the sample is placed in a 2.00L container?

$$PV = k$$

pg.422 problem 2

The pressure of a sample of helium in a 1.00 L container is 0.988 atm. What is the new pressure if the sample is placed in a 2.00L container?

$$P_1V_1 = k = P_2V_2$$

pg.422 problem 2

The pressure of a sample of helium in a 1.00 L container is 0.988 atm. What is the new pressure if the sample is placed in a 2.00L container?

$$P_1V_1 = P_2V_2$$

$$(1.00 \text{ L}) (0.988 \text{ atm}) = (2.00 \text{ L}) (P_2)$$

$$\frac{(\cancel{1.00 \text{ L}}) (0.988 \text{ atm})}{(\cancel{2.00 \text{ L}})} = P_2$$

$$(\cancel{2.00 \text{ L}})$$

$$0.494 \text{ atm} = P_2$$

Charles's Law

Jacques Charles 1746 – 1823

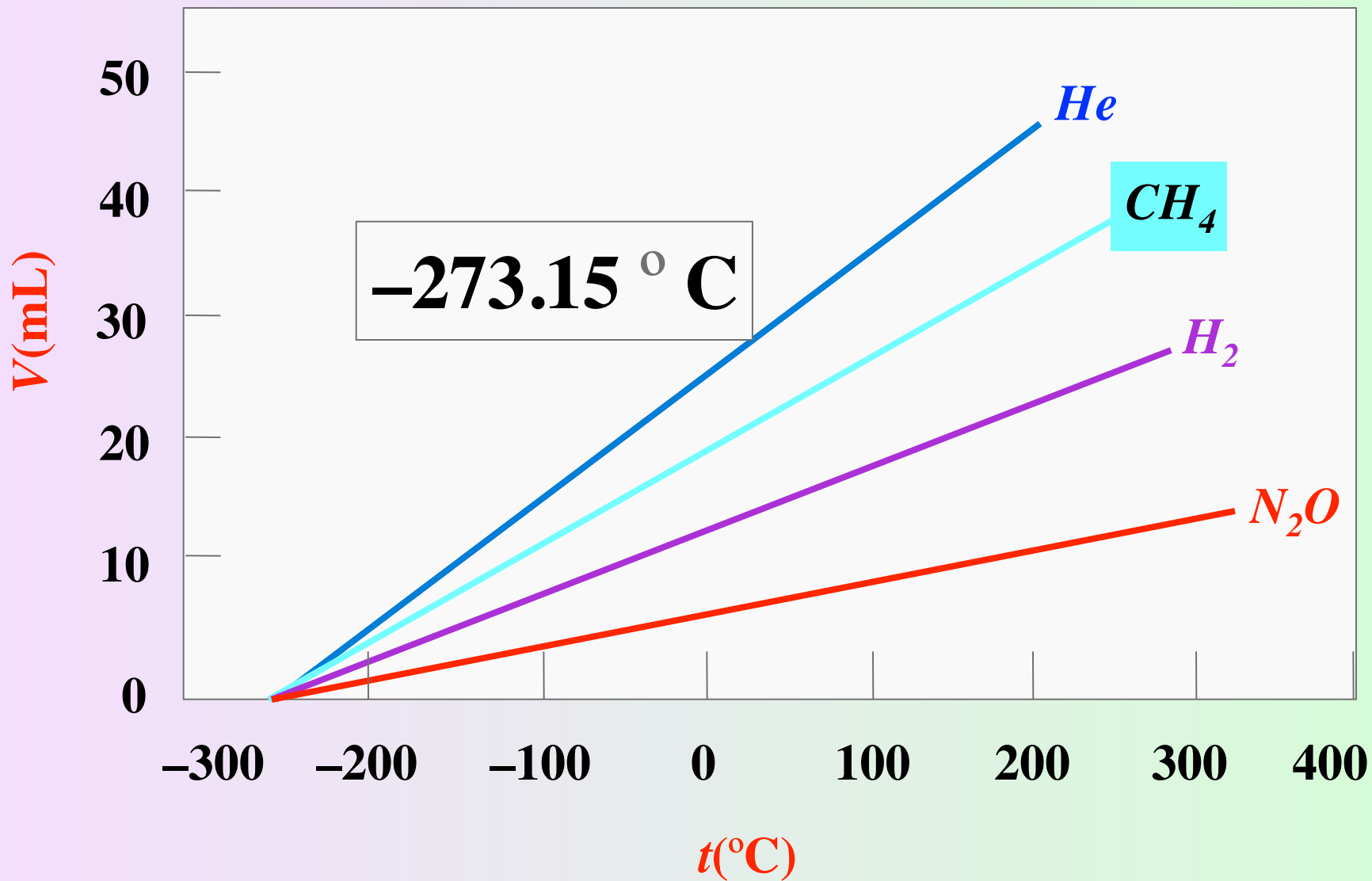
Charles's Law

at constant pressure, the volume of a constant amount of gas is directly proportional to the absolute temperature

constant n , constant P

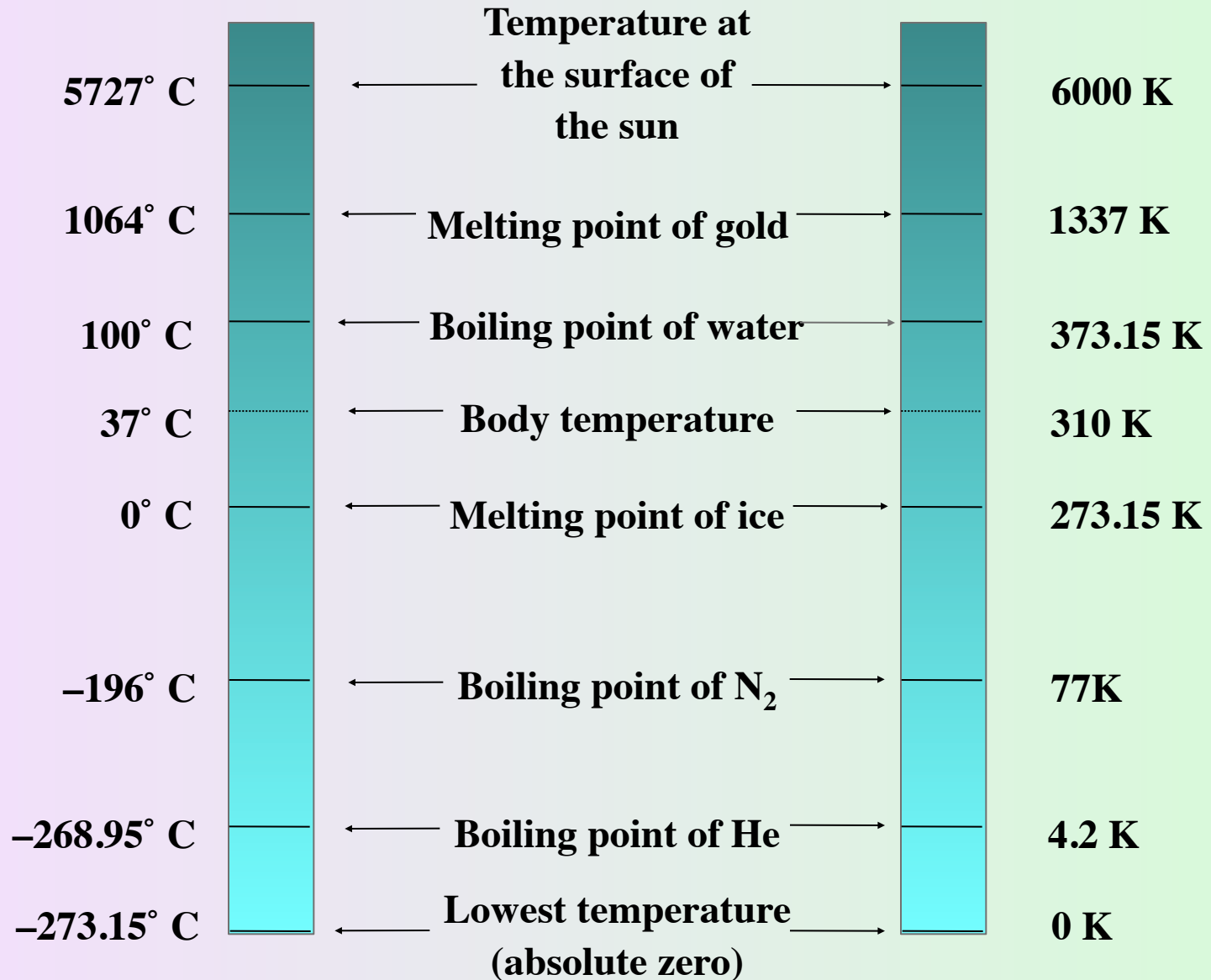
$$V = kT$$

$$\frac{V}{T} = k$$



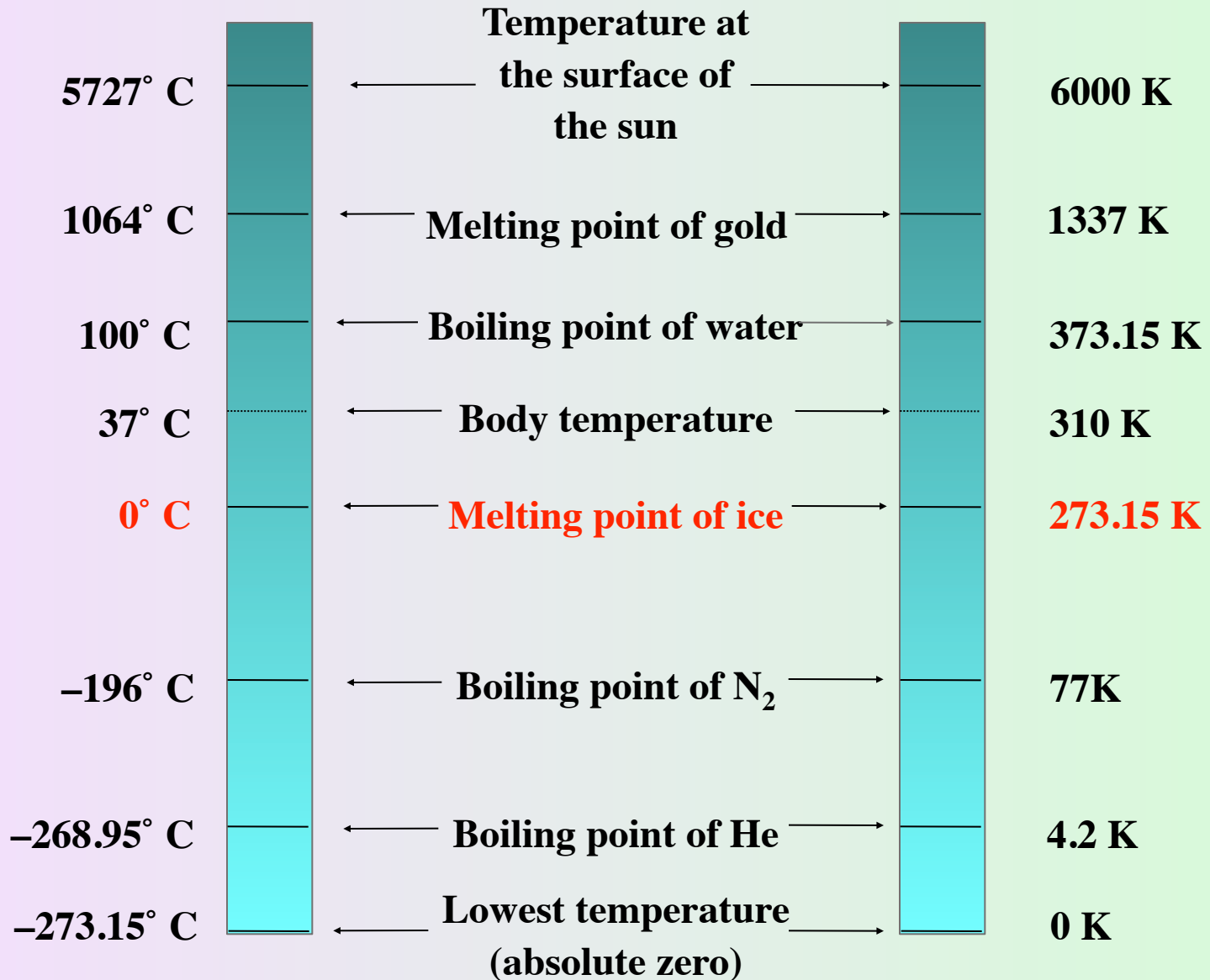
Celsius scale

Kelvin scale



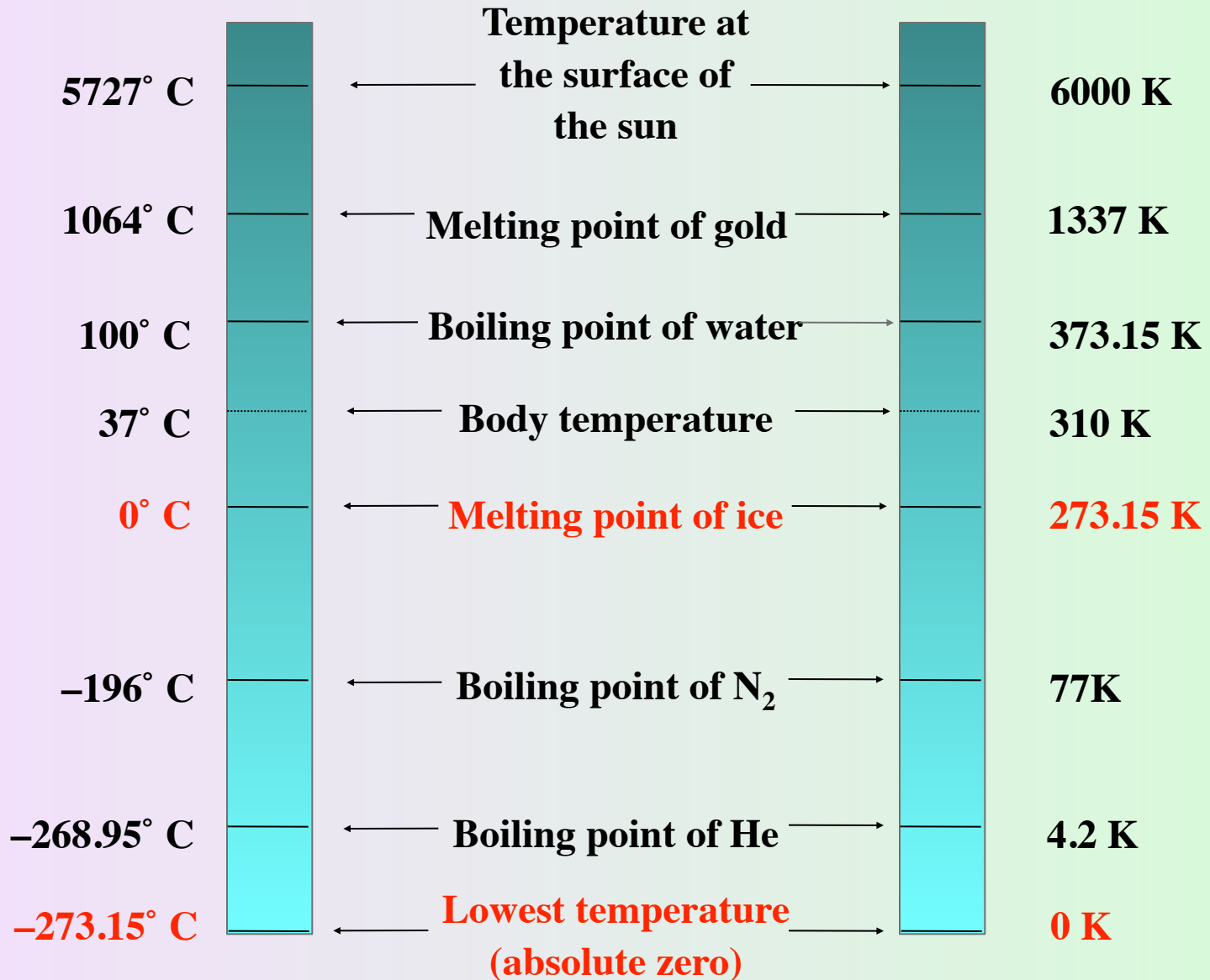
Celsius scale

Kelvin scale



Celsius scale

Kelvin scale



pg.425 problem 6

A gas at 89° C occupies a volume of 0.67 L. At what Celsius temperature will the volume increase to 1.12 L?

$$\frac{V_1}{T_1} = k = \frac{V_2}{T_2}$$

pg.425 problem 6

A gas at 89°C occupies a volume of 0.67 L. At what Celsius temperature will the volume increase to 1.12 L?

$$\frac{V_1}{T_1} = \frac{V_2}{T_2}$$

$$\frac{0.67 \text{ L}}{(89 + 273 \text{ K})} = \frac{1.12 \text{ L}}{T_2}$$

 The temperature must be expressed in Kelvin

pg.425 problem 6

A gas at 89°C occupies a volume of 0.67 L. At what Celsius temperature will the volume increase to 1.12 L?

$$\frac{V_1}{T_1} = \frac{V_2}{T_2}$$

$$\frac{0.67 \text{ L}}{(89 + 273 \text{ K})} = \frac{1.12 \text{ L}}{T_2} \qquad 605 \text{ K} = T_2$$

605 K - 273

$$T_2 = \frac{1.12 \cancel{\text{ L}} (89 + 273\text{K})}{0.67 \cancel{\text{ L}}} \qquad 332 \text{ }^\circ\text{C} = T_2$$

Gay-Lussac's Law

at constant volume, the pressure of a constant amount of gas is directly proportional to the absolute temperature

constant n , constant V

$$P = kT$$

$$\frac{P}{T} = k$$

pg.427 problem 9

A gas in a sealed container has a pressure of 125 KPa at a temperature of 30.0° C. If the pressure in a container is increased to 201 KPa, what is the new temperature?

$$\frac{P_1}{T_1} = k = \frac{P_2}{T_2}$$

pg.427 problem 9

A gas in a sealed container has a pressure of 125 kPa at a temperature of 30.0° C. If the pressure in a container is increased to 201 kPa, what is the new temperature?

$$\frac{P_1}{T_1} = \frac{P_2}{T_2}$$

$$\frac{125 \text{ kPa}}{(30.0 + 273 \text{ K})} = \frac{210 \text{ KPa}}{T_2}$$

$$509 \text{ K} = T_2$$

$$T_2 = \frac{210 \cancel{\text{ kPa}} (30.0 + 273\text{K})}{125 \cancel{\text{ kPa}}}$$

$$509 \text{ K} - 273 =$$

$$236^\circ\text{C} = T_2$$

The Combined Gas Law

Boyle's, Charles's and Gay-Lussac's laws combined into a single law.

constant n ,

$$\frac{P_1 V_1}{T_1} = \frac{P_2 V_2}{T_2}$$

pg.427 problem 9

A helium-filled balloon has a volume of 2.1 L at 0.998 atm and 36°C. If it is released and rises to an elevation at which the pressure is 0.900 atm and the temperature is 28°C, what is the new volume of the balloon?

$$\frac{P_1 V_1}{T_1} = \frac{P_2 V_2}{T_2}$$

$$\frac{(0.998 \text{ atm})(2.1 \text{ L})}{(36.0 + 273 \text{ K})} = \frac{(0.900 \text{ atm})(V_2)}{(28.0 + 273 \text{ K})}$$

pg.427 problem 9

A helium-filled balloon has a volume of 2.1 L at 0.998 atm and 36°C. If it is released and rises to an elevation at which the pressure is 0.900 atm and the temperature is 28°C, what is the new volume of the balloon?

$$\frac{P_1 V_1}{T_1} = \frac{P_2 V_2}{T_2}$$

$$\frac{(0.998 \text{ atm})(2.1 \text{ L})(28.0^\circ \text{ C} + 273)}{(36.0^\circ \text{ C} + 273)(0.900 \text{ atm})} = (V_2)$$

pg.427 problem 9

A helium-filled balloon has a volume of 2.1 L at 0.998 atm and 36°C. If it is released and rises to an elevation at which the pressure is 0.900 atm and the temperature is 28°C, what is the new volume of the balloon?

$$\frac{P_1 V_1}{T_1} = \frac{P_2 V_2}{T_2}$$

$$\frac{(\cancel{0.998 \text{ atm}}) (2.1 \text{ L}) (\cancel{301 \text{ K}})}{(\cancel{309 \text{ K}}) (\cancel{0.900 \text{ atm}})} = (V_2)$$

$$2.27 \text{ L} = V_2$$

Avogadro's Law

Amadeo Avogadro (1776 – 1856)

Avogadro's Law

at constant temperature and pressure, the volume of a gas is directly proportional to the number moles

constant T, constant P

$$V = kn$$

equal volumes of different gases contain equal numbers of molecules

The Ideal-Gas Equation

The Ideal Gas Law

$$PV = nRT$$

constant n , constant T (Boyle's Law)

constant n , constant P (Charles' Law)

constant P , constant T (Avogadro's Law)

The Ideal-Gas Law

$$PV = nRT$$

P is pressure in atmospheres

V is volume in liters

n is number of moles

T is absolute temperature in Kelvins

R is called the gas constant

An ideal gas is a hypothetical gas whose pressure-volume-temperature behavior can be completely accounted for by the ideal-gas equation.

large volumes

high temperatures

Standard temperature and pressure

$$PV = nRT$$

standard conditions defined

$$P = 1 \text{ atm}$$

$$T = 0^\circ\text{C} (273 \text{ K})$$

STP

Standard Molar Volume

The volume occupied by 1 mole of a gas at STP is **22.414 L**

The Gas Constant R

The volume occupied by 1 mole of a gas at STP is 22.414 L

$$PV = nRT$$

$$R = \frac{PV}{nT}$$

$$R = \frac{(1 \text{ atm}) (22.414 \text{ L})}{(1 \text{ mol}) (273.15 \text{ K})}$$

$$R = 0.082057 \text{ (L atm/mol K)}$$

Example

What is the volume occupied by 49.8 g of HCl at STP?

$$49.8 \text{ g HCl} \times \frac{1 \text{ mol}}{36.46 \text{ g}} = 1.366 \text{ mol HCl}$$

$$P = 1 \text{ atm}$$

$$T = 273 \text{ K}$$

$$V = \frac{nRT}{P}$$

$$\frac{(1.366 \text{ mol}) (0.0821 \text{ L atm/mol K}) (273 \text{ K})}{1 \text{ atm}}$$

$$V = 30.6 \text{ L}$$

Example

What is the volume occupied by 49.8 g of HCl at STP? (alternative solution)

$$P = 1 \text{ atm}$$

$$T = 273 \text{ K}$$

$$n = \frac{49.8 \text{ g}}{36.46 \text{ g/mol}} = 1.366 \text{ mol}$$

$$V = \frac{22.4 \text{ L}}{1 \text{ mol}} \times 1.366 \text{ mol}$$

$$V = 30.6 \text{ L}$$

Example

A compound has the empirical formula BH_3 . At 27°C , 74.3 mL of the gas exerted a pressure of 1.12 atm . If the mass of the gas was 0.0934 g , what is its molecular formula?

$$PV = nRT$$

$$n = \frac{PV}{RT}$$

Example

A compound has the empirical formula BH_3 . At 27°C , 74.3 mL of the gas exerted a pressure of 1.12 atm . If the mass of the gas was 0.0934 g , what is its molecular formula?

$$n = \frac{(1.12\text{ atm})(.0743\text{ L})}{(0.0821\text{ L atm/mol K})(27^\circ\text{C} + 273)}$$
$$n = \frac{PV}{RT}$$

$$n = 0.00338\text{ mol}$$

Example (cont.)

A compound has the empirical formula BH_3 . At 27°C , 74.3 mL of the gas exerted a pressure of 1.12 atm. If the mass of the gas was 0.0934 g, what is its molecular formula?

$$n = 0.00338 \text{ mol}$$

$$\frac{0.0934 \text{ g}}{0.00338 \text{ mol}} = 27.6 \text{ g/mol}$$



$\text{BH}_3 = 13.8 \text{ g} /$ empirical
formula

The ideal gas law is often used to calculate the changes that will occur when the conditions of a gas are changed

$$PV = nRT$$

If nRT are constant

$$P = (nRT) \frac{1}{V}$$

$$PV = (nRT) = P_2V_2$$

$$PV = nRT$$

If nRP are constant

$$V = \left(\frac{nR}{P} \right) T$$

$$\frac{V}{T} = \left(\frac{nR}{P} \right) = \frac{V_2}{T_2}$$

The ideal gas law is often used to calculate the changes that will occur when the conditions of a gas are changed

$$PV = nRT$$

If PRT are constant

$$V = \left(\frac{RT}{P} \right) n$$

$$\frac{V}{n} = \left(\frac{RT}{P} \right) = \frac{V_2}{n_2}$$

$$PV = nRT$$

If nRV are constant

$$P = \left(\frac{nR}{V} \right) T$$

$$\frac{P}{T} = \left(\frac{nR}{V} \right) = \frac{P_2}{T_2}$$

Example

A sample of oxygen gas initially at 0.97 atm is cooled from 21 ° C to -68 ° C at constant volume. What is its final pressure.

$$PV = nRT$$

$$\frac{P}{T} = \left(\frac{nR}{V} \right) = \frac{P_2}{T_2}$$

$$\frac{P_1}{T_1} = \frac{P_2}{T_2}$$

Example

A sample of oxygen gas initially at 0.97 atm is cooled from 21 ° C to -68 ° C at constant volume. What is its final pressure.

$$\frac{P_1}{T_1} = \frac{P_2}{T_2}$$

$$\frac{(0.97 \text{ atm})}{292 \text{ K}} = \frac{P_2}{205 \text{ K}} \quad P_2 = 0.68 \text{ atm}$$

Density Calculations

Example

What is the density of UF_6 gas at 62°C and 779mmHg ?

$$\frac{n}{V} = \frac{P}{RT}$$

$$\frac{n}{V} = \frac{\underline{779\text{mmHg}}}{760\text{mmHg/atm} \cdot (0.0821 \text{ L atm/mol K}) (335 \text{ K})}$$

$$= \frac{0.0373 \text{ mol}}{\text{L}} \times \frac{352.03\text{g}}{1 \text{ mol}} = 13.1\text{g/L}$$

A common unit
for gasses

Example

Cyanogen, empirical formula CN, is a gas with a density of 2.335 g/L at 0°C and 1 atm. What is its molecular formula?

$$n = \frac{(1 \text{ atm}) (1 \text{ L})}{(0.0821 \text{ L atm/mol K}) (273 \text{ K})}$$
$$n = \frac{P V}{R T}$$
$$= \frac{2.335 \text{ g}}{0.0446 \text{ mol}} = \frac{52 \text{ g/mol Cyanogen}}{26 \text{ g/mol (CN)}} = 2$$

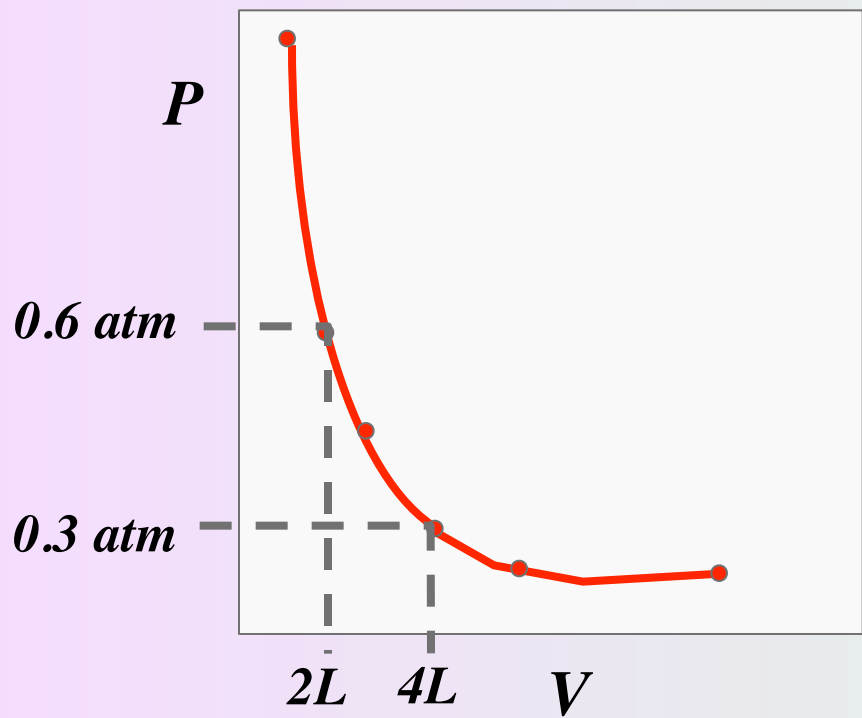
C_2N_2

Plot of P versus V is a hyperbola

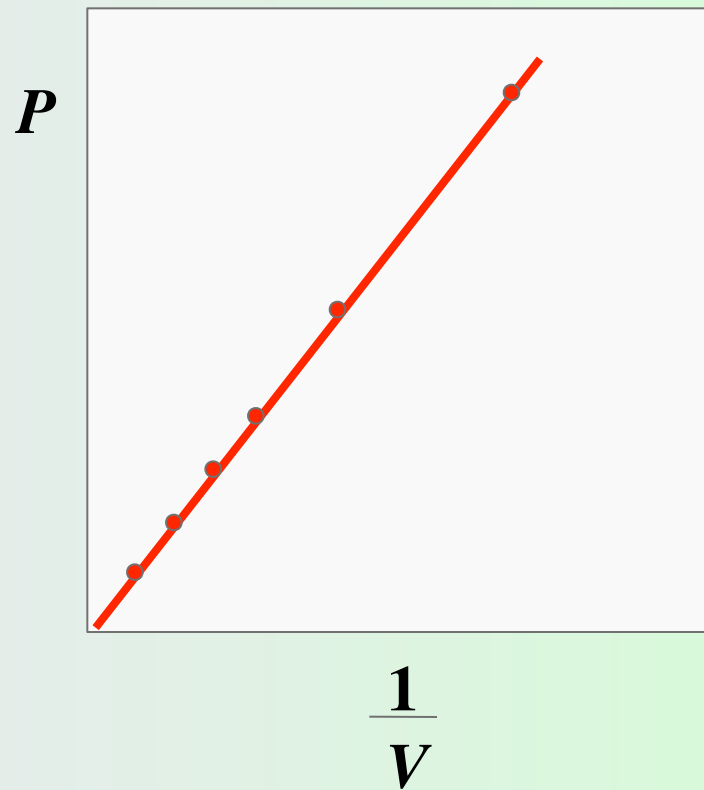
$$PV = k$$

$$P = (1/V) k$$

is of the form $y = mx + b$, which is the equation for a straight line



(a)



(b)

Density Calculations

$$\text{density} = \frac{\text{mass}}{V}$$

$$n = \frac{\text{mass}}{\text{Molar mass}} = \frac{g}{g/mol}$$

$$\frac{n}{V} = \frac{P}{RT}$$

$$\frac{\text{mass}}{\text{Molar mass}(V)} = \frac{P}{RT}$$

$$\text{Therefore: density} = \frac{P}{RT} (\text{Molar mass})$$